

UNITED STATES PATENT APPLICATION

Title:

**PROJECTION ENGINE**

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## PROJECTION ENGINE

## Background of the Invention

### Technical Field of the Invention

The present invention relates generally to light engines for projection display devices, and more particularly to an improvement that takes advantage of color switching and/or both polarizations of light generated by their light sources.

## Background Art

FIG. 1 illustrates a light engine kernel according to the prior art. It includes four polarization beam splitters (PBS's) 101-104 and three spatial light modulators (SLM's), as well as a number of polarizers and filters as needed. A PBS is typically constructed as a cube of glass made from two prisms with an optical coating on their mating surfaces which reflects incoming "S" polarized light and passes incoming "P" polarized light. An SLM is a multi-pixel opto-electronic device that modulates the intensity of light that is imaged to its pixels, by reflecting (or in some embodiments by transmitting) controllable amounts of light independently at each pixel. One embodiment of an SLM is constructed as a liquid crystal on silicon (LCOS) microdisplay. Other embodiments may be constructed as liquid crystal displays (LCD's), digital mirror devices (DMD's), grating light valves (GLV's), or other suitable technologies.

The light engine kernel 100 of FIG. 1 receives an incoming light beam  $L_r$  which has been pre-polarized and pre-filtered into color bands such as those suitable for use in a red-green-blue (RGB) color space. Let the notation “ $Xy$ ” denote color ( $X$ ) and polarization ( $y$ ). The pre-polarization serves to reflect the  $s$  polarization of the incoming light ( $L_s$ ) back to the light source (or for a PBS polarizer redirects it into an absorber). The GM filter serves to rotate the polarization state of the light in the green band  $G_p$  to the  $s$  polarization state  $G_s$ , while leaving the polarization of the light in the blue and red bands unchanged  $B_p, R_p$ . The incoming light arrives at the first PBS 101 which reflects the  $G_s$  component upward and passes the  $B_p$  and  $R_p$  components of the incoming light. The green  $G_s$  light arrives at the second PBS 102, which reflects the  $G_s$  light onto the Green SLM which modulates the  $G_s$  light to insert the green component of the image to be displayed. After passing once through the quarter-wave plate in each direction, the  $G_s$  light will have been repolarized to  $G_p$ , which the second PBS 102 will pass to the fourth PBS 104.

The Bp and Rp components are passed from the first PBS to the third PBS 103, which passes the Bp light through to a Blue SLM and reflects the Rp light to a Red SLM. After being repolarized by the quarter-wave plates, the blue light is reflected and red light is passed to the fourth PBS.

The fourth PBS 104 recombines the green beam with the red/blue beam, to form an output beam.

One disadvantage of this system is that it requires the discarding of one polarization of the input beam. Typically, half of the light source's output is discarded. This reduces the intensity of the output beam and thus the brightness of the image on the screen..

## **Brief Description of the Drawings**

The invention will be understood more fully from the detailed description given below and from the accompanying drawings of embodiments of the invention which, however, should not be taken to limit the invention to the specific embodiments described, but are for explanation and understanding only.

FIG. 1 shows a light engine kernel according to the prior art.

FIG. 2 shows a projection engine according to one embodiment of the invention.

FIG. 3 shows another embodiment of a projection engine according to the invention.

FIG. 4 shows a display system constructed according to the invention.

FIG. 5 shows a 3-D display system constructed according to the invention.

FIG. 6 shows a logical diagram of the projection engine of the invention.

FIGS. 7-12 show construction diagrams of various embodiments of the invention.

## Detailed Description

FIG. 2 illustrates one embodiment of a two-kernel dual polarization projection engine 5 constructed according to the principles of this invention. The projection engine includes a polarization separator 6, a first light engine kernel 8 (Kernel A), a second light engine kernel 10 (Kernel B), and a polarization combiner 12. In one embodiment, the polarization separator is built using a first plate polarizer, the first and second kernels are built using first and second PBS's 32, 48 respectively, and the polarization combiner is constructed using a third PBS 13.

Input light 14 from a light source (Light Source) may be pre-filtered (by conventional means not shown) to substantially eliminate the infrared and ultraviolet, but substantially all of the light in

1 the visible portion of the spectrum may be retained in the input beam rather than being discarded.  
2 Thus, the input beam L<sub>r</sub> may include randomly polarized components G<sub>r</sub>, R<sub>r</sub>, and B<sub>r</sub> (not shown).  
3 The polarization separator reflects the S components L<sub>s</sub> to the first kernel and passes the P  
4 components L<sub>p</sub> to the second kernel. The skilled reader will appreciate that other permutations are  
5 achievable.

6 Kernel A is illustrated as a complete, two-panel system, meaning that it is equipped to  
7 modulate all three colors. A color switch 20 alternately blocks each of two of the colors, and in some  
8 embodiments may switch at a frequency of at least 120Hz. In the mode shown, the color switch 20  
9 switches the red and green components, while the blue component is not switched. For ease of  
10 illustration, switched light components are indicated by dashed lines, while non-switched  
11 components are indicated by solid lines. After passing through the switch, the light may pass through  
12 a filter and clean up polarizer 26, 28. Those of skill in the art will readily appreciate that various  
13 filters and polarizers can be selected to optimize the light engine kernel performance depending on  
14 choices in PBSs and SLMs.

15 The S polarized light L<sub>s</sub> reflected from the polarization separator enters the PBS 32 of the  
16 first kernel, where the non-switched (blue) component B<sub>s</sub> is reflected by the PBS through a  
17 quarter-wave plate 33 to a first SLM 34 (the blue SLM). The first SLM modulates the non-switched  
18 component to insert image content for that color and reflects it back through the quarter-wave plate  
19 to the PBS. The two transits of the blue component through the quarter-wave plate convert it from S  
20 to P polarization. The modulated blue light B<sub>p</sub> then passes back through the PBS toward the  
21 polarization combiner 12. The switched components (red and green) R<sub>p</sub>, G<sub>p</sub> are, during their  
22 respective switching periods, passed through the PBS 32, through a quarter-wave plate 35, and then  
23 to a second SLM 36 (the red/green SLM). The second SLM is coordinated with the switch, to  
24 modulate the light color passed by the switch and insert image content for that color, during that  
25 color's switching period. The modulated light from the second SLM is reflected by the SLM through  
26 the quarter-wave plate into the PBS. The two transits of the red or green light through the quarter-  
27 wave plate convert their polarization from P to S, yielding R<sub>s</sub> and G<sub>s</sub>. The PBS reflects the  
28 modulated and multiplexed R<sub>s</sub> and G<sub>s</sub> components toward the polarization combiner. Thus, at any  
29 given moment, the output of Kernel A includes a modulated non-switched component of a first color  
30 (blue), and a modulated, switched component of one of the other colors (red or green). This beam  
31 may be passed through filters and polarizers as needed, as illustrated generally as 38.

1        The skilled reader will appreciate that the color space, the number of colors, and the selection  
2        of a non-switched color (if any) may be selected according to the needs of the particular application,  
3        and that the particular colors etc. described here are by way of teaching only.

4        Back at the polarization separator 6, the P components are passed to the second kernel 10  
5        (Kernel B), where they pass through a second switch 22. This switch is operated very much like the  
6        first switch of Kernel A. It is not, however, necessary for the same color to be the non-switched color  
7        in both kernels. As shown, red is the non-switched color in Kernel B, and is passed through a second  
8        PBS 48 to a quarter-wave plate 49 and then to a third SLM 50 (red SLM), which modulates the red  
9        light. The switched color components (green and blue) are reflected by the second PBS through a  
10       quarter-wave plate 51 to a fourth SLM 52 (green/blue SLM) which modulates the light to insert  
11       green image content and blue image content during their respective switching periods. The  
12       modulated green and blue light are passed through the PBS to rejoin the non-switched red light. The  
13       second kernel includes filters and polarizers as needed, generally illustrated as 42, 44, and 54, and  
14       the skilled person will readily understand how to select and place them to meet the needs of the  
15       particular application.

16       The modulated light from the first and second kernels arrive at the polarization combiner 12,  
17       where they are combined to emerge as the modulated output beam 16 containing both polarizations'  
18       light components.

19       FIG. 3 illustrates another embodiment of a two-kernel dual polarity projection engine, which  
20       differs from that of FIG. 2 in that it uses three-color switches 60 and 62 rather than two-color  
21       switches, and it uses only a single SLM 66 and 70, respectively, in each of its two kernels. The  
22       three-color switch and single SLM may typically be operated at a frequency above 180Hz, in some  
23       applications.

24       Those skilled in the art will appreciate that the four-panel (four-SLM) projection engine of  
25       FIG. 2 and the two-panel projection engine of FIG. 3 could be combined, yielding a three-panel  
26       projection engine. In such an embodiment, the one panel kernel could operate in a non-switched  
27       manner on one color, or in a switched manner for either two or three colors.

28       FIG. 4 illustrates a display system constructed using a dual polarization projection engine  
29       according to the teachings of this invention. The display system includes one or more light sources, a  
30       dual polarization projection engine, and a display device. The light sources may be any suitable form  
31       of light source, as indicated by the application. For example, the light sources may be arc or plasma

1 lamps, lasers, light emitting diodes, or such. The display device may be any suitable form of display,  
2 such as a rear- or front-projection screen, a heads-up display, or such.

3 FIG. 5 illustrates a different embodiment of the dual-polarization, two-kernel projection  
4 engine, especially adapted for 3-D imaging. As with other embodiments, the projection engine may  
5 optionally include a light source integrally constructed with the rest of the projection engine, or the  
6 light source may be separate. Light from the light source is provided to a polarization separator. A  
7 3-D image typically includes a left-eye image and a right-eye image which, when displayed only to  
8 their respective eyes, are interpreted by the human brain as a three-dimensional image. This may be a  
9 still image, or it may be a moving image. The right-eye image data, Image A, is provided to Kernel  
10 A, and the left-eye image data, Image B, is provided to Kernel B. The kernels inject this content,  
11 such as via SLMs (not shown), and the resulting beams are provided to a polarization recombiner  
12 which combines them into a single output light beam including both polarizations. This output beam  
13 is sent to a display device. Then, by viewing through suitable polarization filters Polarizer B and  
14 Polarizer A, respectively, one of which is S polarized and the other of which is P polarized, the left  
15 eye and the right eye receive only their respective one of the two images of the 3-D image.

16 The skilled reader will appreciate various permutations of this 3-D embodiment, which are  
17 within the scope of this invention. For example, each kernel may be a two-panel or single-panel  
18 kernel, as above.

19 FIG. 6 illustrates another embodiment of a composite-image application of the invention, as a  
20 dual polarization display engine (DPDE). Light from a light source is provided to a polarization  
21 separator, which sends light of a first polarization L1 to a first switch (Switch A) and light of a  
22 second polarization L2 to a second switch (Switch B). Switch A filters L1 into color bands C1-C3  
23 and Switch B filters L2 into color bands C4-C6. Switch A receives a first switch control signal  
24 (Switch Control Signal A), controlling how it switches between at least two of the colors (e.g. C1  
25 and C2) . Switch B receives a second switch control signal (Switch Control Signal B), controlling  
26 how it switches between at least two of the colors (e.g. C4 and C5).

27 Light from the first switch is provided to the first kernel's (Kernel A) one or more first  
28 SLM's (SLMs A) which are fed by one or more image signals (Image Signal A). Light from the  
29 second switch is provided to the second kernel's (Kernel B) one or more second SLM's (SLMs B)  
30 which are fed by one or more image signals (Image Signal B). As above, more than two of the colors  
31 may be switched in any given switch, depending upon the number of colors (say N in Kernel A and

1 Q in Kernel B) that the switch separates the incoming light into and the number of SLMS (say M in  
2 Kernel A and P in Kernel B) that are fed by that switch.

3 In some embodiments, the colors (C1-C3) utilized in the first kernel may be the same as the  
4 colors (C4-C6) utilized in the second kernel, but in different polarization. In some embodiments,  
5 there may be only a subset that are the same. In other embodiments, none are the same. In some  
6 embodiments, the sets of colors provided to the respective kernels are not in the same color space.  
7 For example, the colors C1-C3 may be in the RGB color space, while the colors C4-C6 may be in the  
8 CMY color space.

9 In some such dual-color-space embodiments, it may be undesirable to display both  
10 simultaneously. In such embodiments, one solution is to operate the switch and/or the SLMs of one  
11 kernel to effectively block all of the light in that color space.

12 The skilled reader will appreciate that the switches and/or SLMs may be operated in a  
13 non-binary manner. That is to say, a given color is not necessarily an all-or-nothing proposition. By  
14 adjusting the operation of a switch to selectively reduce the amount of light allowed through in each  
15 color band, a color may be color-balanced versus the other colors in its color space. Color balancing  
16 is well understood in the art of display systems. For example, many CRT based monitors allow the  
17 selection of either a 5000° Kelvin, 6500° Kelvin, or 9300° Kelvin color temperature setting.

18 In some embodiments, the composite image may not be 3-D nor two color space. Rather, the  
19 two images may constitute different portions of a single, larger image, such as a left half and a right  
20 half. As shown in FIG 8, in such embodiments, the polarization combiner does not overlay the  
21 beams, but tiles them.

22 FIGS. 7-11 illustrate various geometric configurations of the various components of the  
23 projection engine. The common theme in them is that each kernel substantially processes a different  
24 polarization of light with the same etendu and in a geometric configuration that allows substantially  
25 identical optical transformation and recombination or tiling into a final image.

26 FIG. 7 illustrates another embodiment in which, instead of the polarization combiner being a  
27 PBS, it is constructed as a second plate polarizer.

28 FIG. 8 illustrates another embodiment in which each kernel processes one half of the  
29 resulting image and tiles each of these images into a final larger image. In this case the SLMs on  
30 each kernel would have one half of the pixels of those in the embodiments described above. This  
31 could potentially reduce the size of the pixels, the size of the SLM, the size of the PBSs and plate

1 polarizers, and thus the cost and complexity of the light engine. In this embodiment, there is no  
2 polarization combiner, and a reflective means such as a plate polarizer (second plate polarizer) is  
3 positioned to be outside the light path of the output of the second kernel. In this configuration, light  
4 from the first kernel is directed onto a first display and light from the second kernel is directed onto a  
5 second display. In most embodiments, there will be substantially no overlap and substantially no gap  
6 between the images on the first and second displays, to present a substantially seamless image. The  
7 first and second displays may be areas of a single, unitary display.

8 FIG. 9 illustrates, in a geometrically stylized format, one embodiment in which, rather than a  
9 polarization separator, a pair of light sources are used. Light from the first light source (Light Source  
10 A) has a first polarization and is directed to a first polarization switch-equipped kernel (Kernel A).  
11 Light from the second light source (Light Source B) has a second, different polarization and is  
12 directed to a second polarization switch-equipped kernel (Kernel B). The modulated output beams  
13 from the kernels are provided to different sides of a polarization combiner, which merges them into a  
14 dual polarization output image. In one such embodiment, the light beams from the light sources cross  
15 each other before entering their respective kernels. In other embodiments, they may not. For  
16 example, one or both of the kernels could be constructed to receive its input light at an outer surface  
17 rather than an inner surface. In such embodiments, the light source(s) would be positioned outside  
18 the structure, in a position opposite their illustrated position in FIG. 9.

19 FIG. 10 illustrates geometry of another embodiment. The overall structure has a rectilinear  
20 (and preferably square) shape, with first and second polarization switch-equipped kernels at  
21 diagonally opposing corners, with the polarization separator and polarization combiner at the other  
22 corners. The light source (not shown) is external to this structure. The structure (including the  
23 various switches, filters, polarizers, and so forth) may be fabricated as a monolithic, integral unit. In  
24 one such mode, all four major components – polarization separator, two kernels, and polarization  
25 recombiner – are constructed as PBSs.

26 FIG. 11 illustrates another embodiment in which only one of the kernels is switched  
27 (meaning only one of the kernels has more colors than SLMs), while the other kernel is  
28 non-switched. Again, the kernels are at diagonally opposed corners of the generally rectilinear, and  
29 preferably square, overall shape. The non-switched kernel would have only one SLM and would  
30 utilize only one of the colors used in the switched kernel. In some such embodiments, the

1 non-switched kernel may operate on a weaker color, or one whose intensity it is desired to boost by  
2 combining both polarizations at the output.

3 FIG. 12 illustrates another embodiment in which the overall structure is not constructed as a  
4 monolithic unit. Such an embodiment may be desirable in applications in which the four basic blocks  
5 (polarization separator, two kernels, and polarization combiner) behave differently with respect to  
6 heat. For example, in the embodiment shown, one of the kernels (Thermally Similar Kernel) has e.g.  
7 thermal expansion properties which sufficiently match those of the polarization separator and the  
8 polarization combiner, while the other kernel (Thermally Different Kernel) does not. If these four  
9 were bonded together into one monolithic whole, there might be unwanted mechanical stresses as the  
10 structure heated up under use, which could, for example, damage one of the PBS's or SLM's or  
11 switches. In order to mechanically isolate the different unit, it is left surrounded by an air gap,  
12 permitting it to expand and contract on its own, while the others are joined with a suitable bonding  
13 material for mechanical strength and reliable alignment. The reader will appreciate that any or all of  
14 the blocks could be separated by air gaps, not necessarily one of the kernels.

15 While, for the sake of clarity and explanation, the various aspects of the invention have been  
16 described and shown with reference to specific embodiments, the skilled reader will appreciate that  
17 various details thereof may be modified within the scope of the invention. For example, in some  
18 applications it may be desirable to have a two-panel kernel which switches all three colors, such as  
19 by switching one SLM between blue and red and the other between green and red, such that red is  
20 continuously imaged, on alternating SLMs in turn, for increased brightness in the red.

21 And while the invention has been described in terms of human-visible light, it may certainly  
22 be practiced in other electromagnetic wavelengths.

23 While the invention has been described as switching between colors at a 50:50 duty cycle and  
24 then using other means to perform color balancing, the color balancing could instead be done by  
25 adjusting the duty cycle. In such embodiments, the "non-switched" color could in fact be switched –  
26 not against another color, but against no color, simply to reduce its SLM time and perceived  
27 intensity.

28 Although the various embodiments have been described above as having at least one  
29 switched kernel, there is at least one application in which no switching is required. If there exists at  
30 least one color which is present, in different polarizations, in both kernels, and the polarization  
31 combiner overlays the kernels' output beams, the intensity of that at least one color is substantially

1 doubled. It is believed that in the prior art, there was no case in which a same color was handled by  
2 both of the "kernels" (including the cases where a polarization's path involved less than a complete  
3 kernel).

4 Reference in the specification to "an embodiment," "one embodiment," "some  
5 embodiments," or "other embodiments" means that a particular feature, structure, or characteristic  
6 described in connection with the embodiments is included in at least some embodiments, but not  
7 necessarily all embodiments, of the invention. The various appearances "an embodiment," "one  
8 embodiment," or "some embodiments" are not necessarily all referring to the same embodiments.

9 If the specification states a component, feature, structure, or characteristic "may", "might", or  
10 "could" be included, that particular component, feature, structure, or characteristic is not required to  
11 be included. If the specification or claim refers to "a" or "an" element, that does not mean there is  
12 only one of the element. If the specification or claims refer to "an additional" element, that does not  
13 preclude there being more than one of the additional element.

14 Those skilled in the art having the benefit of this disclosure will appreciate that many other  
15 variations from the foregoing description and drawings may be made within the scope of the present  
16 invention. Indeed, the invention is not limited to the details described above. Rather, it is the  
17 following claims including any amendments thereto that define the scope of the invention.